Continents

- If we remove the ocean water......
- What features do we see ?
- **Continents** are the dominant feature
  - surface area ~1/3
  - flat tops
  - elevation close to sealevel
  - steep sides (not gradually tapered)

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- What causes the relief between the two types of plates ?
Continents and Seafloor

- **Continental crust**
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- **Mantle material**
  - peridotite
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Southern California Coast: Continental Shelf

- Continental shelf is cut by submarine canyons that channel sediments to the deep ocean.
- What keeps continental edges so steep?
Mountain Belts

- Mountain belts are chains of mountain ranges 1000s of km long
  - Located along the edges of continents

- As mountains grow higher and steeper, erosion rates increase (from running water and ice)
• Ancient mountain belts have eroded nearly flat to form the stable core of a continent (craton or shield)

• Every continental plate has a central, old, craton.
Growth of Continents

- Continents grow larger as mountain belts evolve along their convergent margins

- New accreted terranes can be added to older cratons with each episode of convergence

- Tectonic subduction participates in growth and shape of continents
Erosion rates
Tectonics
Isostacy (gravitational collapse)
ALL play a role in shaping the continents into what we see today.
(mountains rise, but don't stay high too long)
Seafloor Bathymetry

• Seafloor plates are 100-10,000 km wide.
• Seafloor plates don't have clear edges or breaks
• Features: *spreading ridges* (2-3 km below sea level)
• Features: *submarine plateau(x)*
  - ridge and plateaus have larger crustal thickness
  - some have continental “type” crust, most are basaltic

*Are there mountains on the seafloor?*
Ridge migration is shown to have little effect on upwelling and melting rates.

Toomey et al., 1998; Conder et al., 2001
Southern Cross Seamount  
(south Pacific)


Many seamount chains oriented perpendicular to spreading display regular spacing (Bach smts ~30 km).
Seamount Chains in the South Pacific

Sojourn Ridge, Hotu Matua, Pukapuka Ridge, spacing = 200 km

Rano Rahi smts spacing = 20 km
Seamounts

- Seamounts can stand ~1/2 the height of Mt. Everest
- Some are linear (some not)
- Some have age progressive volcanism (some don't)
- Some start or stop at plate boundaries
- Some start and stop mid-plate
- Most seamounts occur far from plate boundaries
- What is responsible for producing them?

- Mantle plumes (hot spots)
- Mantle plumes probably don't create all seamounts!
- Scientists must think of other geodynamic models
- Can you think of any?
- Outer-rise of subduction “bend”
- Asthenospheric flow
Models for Intraplate Seamount Chains

(a) SMALL SCALE CONVECTION
(b) EXTENSION

(c) THERMAL CONTRACTION

(d) VISCIOUS FINGERING

High µ depleted asthenos
Low µ
GLIMPSE Experiment
(Gravity Lineations and Intraplate Melting Petrology and Seismic Expedition)

COOK16/Melville November, 2001
VANC04/Melville November, 2002

Brown University
Lamont Doherty Observatory
Oregon State University
Low viscosity fluid displaces high viscosity fluid by fingering instabilities. (Hill, 1952; Saffman and Taylor, 1958)

Governing Equations for Saffman-Taylor Instabilities

An applied pressure gradient is described by Darcy flow

\[ \frac{\Delta P}{\Delta x} = \rho g - \mu U/b^2 \]

For two component flow:

\[ P_1 = P_0 + \rho_1 g \delta x - \mu_1 U \delta x/b^2 \]
\[ P_2 = P_0 + \rho_2 g \delta x - \mu_2 U \delta x/b^2 \]

\[ \Delta P = [ (\rho_1 - \rho_2) g \delta x - (\mu_1 - \mu_2) U / b^2 ] \delta x \]

Density variations are neglected for horizontal flow.
\[ \delta P = (\mu_1 - \mu_2)U \frac{\delta x}{b^2} \]

The interface is unstable for \( \mu_1 / \mu_2 > 1 \)
Experimental Apparatus

* Working fluid is corn syrup diluted with water.
* Viscosity ratio $\mu_1/\mu_2$ ranges from 5 to 300.
* Experimental time ranges from 2 min – 5 hr.
* The diffusion coeff is small, $1 \times 10^{(-10)} \text{ m}^2/\text{s}$

Variations in plate spacing, injection rate, and viscosity ratio are considered.
Radial Flow Between Stationary Plates

* The pattern of fingering is established by perturbations at early times.
* Growth of instabilities occurs by spreading, shielding, and tip splitting.
* Fingering wavelength is controlled primarily by plate spacing.

Viscosity ratio = 200 (200 / 1 Pas)
### Rate of mass flux

<table>
<thead>
<tr>
<th></th>
<th>Rate of mass flux</th>
<th>Plate velocity</th>
<th>Mass flux / (V_{plate} \times b \times R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laboratory</td>
<td>0.50 g/s</td>
<td>0.04 cm/s</td>
<td>30 - 300</td>
</tr>
<tr>
<td></td>
<td>0.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper mantle</td>
<td>3.3 Mg/s</td>
<td>10 cm/y</td>
<td>0.01 – 0.2</td>
</tr>
</tbody>
</table>

(Marquesas, Tahiti (Sleep, 1990))
Mobile Upper Boundary

* Fingers align with shear and travel both downstream and upstream.
* Fingers initially growing perpendicular to shear are damped out.
* Asthenospheric flow may be a model for formation of linear seamounts.

Viscosity ratio = 200

movie
Broad Long Wavelength Topographic Swells

- Hawaii and east Africa are examples of regions which exhibit large scale topographic swells
- Rising *mantle plumes* are suggested as the cause
Global Free Air Gravity Map

Smith and Sandwell
Gravity

• Is the value of gravity at the Earth' surface the same everywhere?

• What causes any differences?

  • Gravity varies by about 0.05% over the surface of the Earth

  • Causes are due to differences in density within the Earth's interior

  • Continental roots
  • Subducting slabs
  • Convection
  • Upwelling plumes
Gravity

• How is gravity measured?

• Gravimeters on land
• Gravimeter towed behind ships
• Satellite orbits are perturbed
• Satellites Altimetry use radar reflections off of sea surface

• Which are the highest resolution?
Gravity

[Graph showing the gravity (mgal) with high density indicated by a brown circle]
Gravity

- Elevation, at greater distance from the Earth's center
- Will have lower gravitational attraction
Gravity

- Gravity is also sensitive to the **excess mass** of the mountain root.
- The combined attraction is somewhere in between.
- It is important to consider **gravity** simultaneously with **topography**.
Do these map have similar highs and lows everywhere?
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Asthenosphere
High µ depleted asthenos
Low µ lithosphere
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0

-4

high density
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Comparing Gravity and Topography

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